A Fossil Flora from Pagan, Mariana Islands[1]

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Pyroclastic deposits on Pagan, northern Mariana Islands, contain numerous plant impressions. During geologic investigations in 1954, ten collections were made for subsequent identification and study. Seventeen plant species, all of which now live in the Marianas, have been distinguished.

The geologic investigations of Pagan were undertaken by a field party of the Office of the Engineer, U. S. Army Forces, Far East, staffed by members of the U. S. Geological Survey. L. D. Bonham of the field party first noted the plant fossils. Gilbert Corwin, with the aid of M. J. Terman, also of the field party, and Santiago V. Castro, a resident on the island, collected samples and made field studies of the fossil localities. Fosberg has identified, studied, and described the plant impressions.

LOCATION AND GEOGRAPHY

Pagan Island is near the center and is the largest of the northern Mariana group. It lies between latitudes 18°01′ and 18°11′ North and between longitudes 145°41′ and 145°49′ East, about 280 miles north of Guam and 1,100 miles south-southeast of Tokyo, Japan (Fig. 1).

The northern Mariana Islands form a chain nearly 300 miles long that consists of the summits of large volcanoes rising from ocean depths of as much as 6,000 feet. Uracas (Farallon de Pajaros) at the north end is one of the most active volcanoes of the western Pacific. Pagan, Asuncion, Agrigan, and Guguan have had eruptions since 1900 (Tanakadate, 1940). The islands are generally small, relatively high, and rugged. The maximum elevation of 3,136 feet is at the summit of Agrigan Volcano.

Pagan consists of two active volcanic centers located within broad circular depressions (calderas) that are connected by a high rugged isthmus. It has an area of 18.4 square miles and a greatest elevation of 1,890 feet near the south end of the isthmus.

The northern caldera is 3½ miles in diameter and has one large central cone, Mt. Pagan, that has an elevation of 1,855 feet. Relatively recent basalt flows are extensive and form broad plains north, east, and south of the volcano; ash is concentrated to the west (leeward).

The southern caldera is about 1½ miles across. South Volcano within it consists of four coalescing cones, three of which have broad steep-sided craters. Rough lava plains bound the volcano on the north, east, and south. To the west the volcano slopes directly to the ocean.

The isthmus ranges in width from about ½ mile at the north end to 1 mile at the south end. Northward along the crest of the isthmus, the peaks become successively lower. The caldera backslopes north of the isthmus are dissected by numerous valleys directed away from the rim of the northern caldera.

The volcanic rocks have been divided into two major groups: pre-caldera and post-caldera. Both consist of flows and pyroclastic rocks.

The older, pre-caldera group is well exposed in the caldera walls, along the coasts of the isthmus and southern end of the island, and in old sea cliff remnants north and northeast of Mt. Pagan (Fig. 1). The lavas and pyroclastic rocks are products of eruptions by at least four major volcanoes and a number of minor vents aligned along or near the axis of

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the island. The largest of the old volcanoes was probably in the position of the present Mt. Pagan. The uppermost unit of the succession is composed of a widespread thick tuff-breccia sequence.

The pre-caldera group is probably of late Quaternary age. Sea cliffs have been cut in the breccias and older deposits; and reef limestones, some of which are now as much as 5 feet above present sea level, have since been deposited on the wave-cut platforms. Similar sea cliffs flanked by terraces and raised reef limestones have been noted on the coasts of many Pacific islands and are attributed to erosion and deposition during post-glacial high stands of sea level. Sea levels 5 to 12 feet higher than the present one have been assigned various dates ranging from about 1,000 to 5,000 years ago. Some plants that may have been introduced by man are represented by impressions in samples collected from the upper breccias and therefore may indicate a maximum age for these breccias of about 4,000 years—the probable length of time since the advent of man in Micronesia (Spoehr, 1955*a*, 1955*b*).

The post-caldera succession is concentrated within the calderas. At some places lavas have flowed over the caldera rims; tuff as much as 30 feet thick mantles large portions of the caldera blackslopes and the isthmus.

Historic records of eruptions are scattered, conflicting, and incomplete. It is likely that several major eruptions have taken place within the past 200 to 300 years. Marche (1891: 261) states that a major eruption occurred in 1872. Extensive lavas northeast and southwest of Mt. Pagan and a thick tuff sequence to the west were probably deposited at this time. Eruptions since 1900 have been minor.

VEGETATION

The present-day vegetation of Pagan gives a general impression of semi-aridity. This is probably not so much a reflection of climatic dryness as of an extremely porous substratum and of the pioneer nature of vegetation, which occupies surfaces of recent volcanic ejecta. In the very few low, wet areas, such as to the west and southwest of the Inner Lake, thickets of broad-leafed trees are luxuriant enough, and places bordering the lake are somewhat marshy. Luxuriant patches of woods also exist in hanging valleys on the west side of the south end of the island. A mixed scrub forest of low stature forms thickets and patches up to several acres in extent on plains north and south of Mt. Pagan — extending up its lower slopes in places on steep slopes on the west shore of the isthmus, and in numerous ravines throughout the island. There has been no investigation of the actual composition of this forest, but it contains 15 or more species of trees.

The loose volcanic ash that covers large areas, especially on the west side, is largely vegetated by an almost pure stand of swordgrass, *Miscanthus floridulus* (Labill.) Warb. This forms a coarse, harsh, brake-like grassland 1 to 3 m. tall and very dense in places. On the steepest slopes and above 250 m. altitude this grass tends to be shorter and the clumps more widely spaced. Above 450 m. it is sparse to absent.

Lava flows may be practically bare, as on the northeast side of Mt. Pagan; they may support scattered clumps of *Miscanthus* and trees of *Casuarina*, as on the east and southeast sides of Mt. Pagan and the central upland of the southern part of the island; or, as on many of the flows and lava cliffs to be seen along both sides of the island, they may be covered by almost pure forests of *Casuarina*. *Casuarina* and the fern, *Nephrolepis hirsutula* (Forst. f.) Presl, are among the earliest invaders on new lava. Both species were well established on a fresh black *aa* flow in the depression at the west base of Mt. Pagan in 1950. This flow has been dated by Tanakadate (1940) as having occurred in 1925. It shows no visible weathering.

On plains of ash soil the vegetation is gen-

erally grassland with scattered trees or clumps of trees. The trees may be *Pandanus*, *Casuarina*, or any of a number of broad-leafed species. Many of these areas were under cultivation before World War II and are weedy and have rows of *Casuarina* and other trees planted by the Japanese as windbreaks. *Jatropha gossypifolia* L., a fleshy-stemmed shrub introduced by the Japanese in the 1930's, has spread and now dominates large areas in the central part of the island. Clumps of trees of various kinds mark the sites of houses, still existing or not. On the gently sloping northwest part of the island is a large coconut plantation. There are smaller ones in many parts of the island, both on plains and on talus cones. Coconuts are also common in ravine mouths and on steep slopes above the sea. The large plantations are of relatively recent date, but there is no way of knowing the age of smaller clumps of coconuts that are mixed with other vegetation on various parts of the island. Some may very well date from before European visits to the island.

FOSSIL LOCALITIES

All samples of plant impressions are from the northern half of the island, mostly from tuff of the pre-caldera succession. Impressions were noted in talus blocks at the foot of a high cliff at the south end of the island but no specimens were obtained. One sample (PC-86) was collected from post-caldera tuffs forming the surface of a terrace northeast of the bisected tuff cone; other impressions in post-caldera deposits were observed on the uplands east of the cone.

Samples from the pre-caldera succession represent several stratigraphic horizons (Table 1). Most collections are from tuffs that underlie or are included in an extensive tuff-breccia sequence near the top of the succession. One of the most accessible localities (PC-43) is at a sharp bend in the trail at the west end of the caldera rim. Three samples (PC-58, PC-79, PT-7) are from tuffs associated with lavas or volcanic breccias that underlie the upper breccias.

Impressions of tree trunks were observed near the base of the upper breccias at several places (Fig. 2). In all cases the impressions are nearly horizontal and therefore represent fallen branches and trunks. Many are oriented about parallel to radii from Mt. Pagan, suggesting that a powerful explosion from the mountain felled the trees.

THE FOSSIL PLANTS

Almost the entire collection consists of leaf impressions, most of them fragmentary. Some of these have no features preserved that would make possible even tentative determinations. Very careful scrutiny shows that in the entire

Fig. 2. Tuff overlying lava and underlying tuff-breccia at the west end of the caldera rim. Plant impressions were collected from the tuff below and interbedded with the dark colored cindery layers in the upper part of the picture. The hole in the cindery layer was probably formed by decay of a tree trunk that had been buried by the ash. The sides of similar holes elsewhere commonly retain impressions of tree bark. A deformed tuff layer near the center of the picture may represent the soil horizon in which the plants grew.

TABLE 1
AGE SEQUENCE OF SAMPLES CONTAINING PLANT FOSSILS, COLLECTED ON PAGAN ISLAND

NUMBER	AGE AND LOCALITY*	LITHOLOGY	STRATIGRAPHIC RELATION
PT-7	Pre-caldera; Togari Peninsula.	Well-indurated, reddish, fine-grained, laminated tuff.	Tuff associated with breccia underlying thick flow and cinders of a minor vent; underlain by thick succession of lavas and pyroclastic rocks derived from old volcano to southeast.
PC-58	Pre-caldera; Togari Peninsula.	Same.	
PC-79	Pre-caldera; north end of island.	Poorly consolidated brownish tuff containing numerous pellets. Some fine-grained yellow to reddish soil layers associated.	Tuff overlain by pre-caldera lavas which are overlain in turn by the upper breccias. Underlying tuff breccias mostly covered by talus.
PC-43	Pre-caldera—base of upper breccia sequence; west coast, west end of caldera rim.	Poorly consolidated brownish to gray tuff and cindery tuff. Local coarse cinder beds (Fig. 2).	Overlain by 80-foot thick tuff-breccia sequence; underlain by 8 feet of tuffs that are underlain by lavas (Fig. 2).
PC-48	Pre-caldera—base of upper breccia sequence; west coast ½ mile south of monument on Bandeera Peninsula.	Same as PC-43.	Similar to PC-43.
PC-84	Pre-caldera—base of upper breccia sequence; east coast, ½ mile NE of bisected tuff cone.	Brownish, poorly consolidated, fine tuff.	Overlain by thin pellet tuff that is overlain by tuff-breccia; underlain by gray ash, a yellow-orange soil, and lava flow.
PC-85	Pre-caldera—within upper breccia sequence; same locality as PC-84.	Coarse, gray, poorly consolidated tuff with numerous large grains, rock fragments, and voids.	Overlain by tuff-breccia; underlain by pumice bed, 1-foot thick.
ID-2	Pre-caldera—base of upper breccia sequence; east coast, north side of Togari Peninsula.	Tuff similar to PC-84.	Overlain by thin tuffs that are overlain by tuff-breccias; underlain by ash, soils, and thick sequence of very fine tuff-breccia (lapilli tuff).
ID-3	Pre-caldera—within upper breccia sequence; specimens from talus blocks on slope.	Coarse, brownish tuff.	Near middle of tuff-breccia sequence; underlain by pumice bed, 1-foot thick.
PC-86	Post-caldera—recent tuff forming surface of terrace ½ mile NE of bisected tuff cone.	Brown, coarse, granular 6-inch tuff layer that is moderately indurated at surface but loose and friable a few inches below.	Overlain by pellet tuffs and locally by beach sands and wash; underlain by mixed loose ash and beach sand.

* See Figure 1.

collection less than 20 different species are distinguishable. Some species are represented by many pieces in various states of preservation.

In most instances the venation of the leaves provides the best distinguishing character. Margins are rarely well preserved and do not help much in identification. General shape, apparent texture, cross section, character of surface, and curvature are sometimes pertinent. It is obvious that with such material it would be hopeless to attempt identification

unless the probable flora were very restricted. The fact that the deposits are considered relatively recent makes reasonable the assumption that the flora was not much different from the present flora of the Marianas. It must be borne in mind, however, that any determination of material of this sort should be regarded as tentative. In the list that follows, those species which were not in any horizon represented by fairly well-preserved material are indicated by question marks. In the lists under the separate sample numbers, species not represented in the known present-day flora are marked by asterisks.

Those remains which presented no features that could suggest any hope for identification have been disregarded. Of the remainder the better specimens in all samples have been retained for deposit in the U. S. National Museum. Of these, all have been identified except two. One of these is probably a leaf scar of a compound leaf, which has not been matched; the other is either a mold of a fruit or an impression of a strongly curved or distorted leaf.

In addition to the specimens collected, molds of tree trunks, probably *Pandanus* judging from the abundant transverse leaf scars surrounding the trunks, were noted in several horizons.

In the following list of species the specimen numbers cited immediately below the name of each species are made up of the collector's sample number with an arbitrarily added number designating material of similar appearance in a sample and letters indicating the various pieces as labelled for deposit in the U. S. National Museum.

POLYPODIACEAE

Pteris quadriaurita Retz.

PC-79–1 (a–f)

Abundant fragmentary leaf impressions showing very clearly the shape and arrangement of pinnules and fairly complete pinnae (Fig. 3).

This fern is widespread in the western Pacific and is found on Pagan today. It occurs in shaded places but at times under relatively dry conditions. It is surprising that such a delicate plant should be so well preserved.

PANDANACEAE

? *Freycinetia mariannensis* Merr.

PC-85–3, PC-79–5

PC-79–4 (a–k) (?)

Fragmentary leaf impressions (Fig. 4), very difficult to distinguish from those of *Pandanus tectorius*. Leaf veins 10 to 15 per cm., equally spaced clear to margin, little or no plication apparent, width up to 4 cm. Impressions showing neither plication, rolled margins, nor crowding of veins toward margins have generally been placed here. Some of these, however, where the venation is not clear, could possibly be *Pandanus tectorius*.

This species is found in the well-explored parts of the Marianas as far north as Pagan

Fig. 3. *Pteris quadriaurita*, fragmentary impression of frond showing portion of rachis, pinnae, with pinnules.

FIG. 4. ? *Freycinetia mariannensis*, portion of central section of leaf, showing venation.

and Agrigan. It has relatives throughout the Indo-Pacific region. It grows in woods and ravines and is a liana climbing on trees and rocks.

Pandanus tectorius Park.

(*P. fragrans* Gaud., *P. Kafu* Mart.)
PC-79–3 (a–h), PC-79–2 (?), PC-86–4 (a–f), PC-43–4 (a–d), PC-43–10, PC-43–11 (a–c) (?), ID2 (F)-6 (?), ID 2 (F)-2

Abundant fragmentary leaf impressions, many of them showing venation, many showing characteristic plications, some showing curled margins characteristic of dried leaves (as found under the trees), and several representing the narrow prolonged part near tip. Numbers PC-43–11 and ID2 (F)-6 seem to be fragments of the enlarged curved bases of the leaves, but this identification is not certain. Number PC-79–2 seems to be a fragment of an impression of a fruit of this species. This also is not certain. Margins have not been preserved in good condition in any of the material. The veins are generally more crowded especially near the margins, than in *Freycinetia*, varying from about 17 to 26 per cm. depending on the position in the leaf and are closer together toward the apex and near the margins. The veins, except the midrib, are of about equal strength (Fig. 5).

The tree trunk molds seen probably also belong here.

This tree is very common on the Marianas, including Pagan, and is found throughout the tropical Pacific islands, mostly at low altitudes. It is an important component of many forests and is also found scattered in grasslands. Its frequency in this collection could be due both to its abundance and to the hard stiff leaves that lend themselves to preservation as impressions.

FIG. 5. *Pandanus tectorius*, portion of central section of leaf.

GRAMINEAE

Miscanthus floridulus (Labill.) Warb.

PC-43–6 (a–p), PC-43–7 (?), PC-43–8, PC-43–9 (a–b), PC-48, PC-79–7 (a–e), PC-79–8 (a–b), PC-84–1 (a–d), PC-85–4 (a–d), PC-36–5, ID2 (F)-1 (a–k), $ID3_1$-1

Abundant fragments of leaf impressions, as well as a few pieces of stem and leaf-sheath impressions. The leaves are thin and in addition to a heavy midrib have two orders of lesser veins, with the most prominent of these at equal intervals, about 9 to 6 mm. In each interval are 3 to 4 very distinct smaller veins. These blades are mostly 1 to 2 cm. wide, but several are much wider than that, so that it is hard to match them with available herbarium material. However, there seems little doubt that they represent this species. The sheaths show a curved surface, no midrib, and slightly irregular veins, about 16 in 5 mm. A mold of such a sheath shows a slight amount of compression and somewhat of a keel, or angle, as is commonly observed on the back of sheaths in this species. The poorly preserved stem fragments are not especially distinctive.

The leaves of this species are the most abundant fossils in the collection (Fig. 6). In some cases they are arranged so regularly as to suggest the pinnae of a palm or the plications of a fan palm leaf. The venation, however, is very characteristic and is easily matched in herbarium material.

This is the most abundant living plant on Pagan, where it dominates large areas of grassland, especially on loose volcanic ash soils. It is a coarse harsh grass as much as 2 to 3 m. tall. It is found from Japan and the Philippines to New Caledonia and east throughout Micronesia and Polynesia (except Hawaii) on volcanic islands.

PALMAE

Cocos nucifera L.

PC-79–6

This is the impression of a strongly plicate single bent section of a seedling leaf (Fig. 7). The size of the leaf and the amplitude and character of the plications match exactly a segment of a seedling coconut leaf preserved in the Bailey Hortorium of Cornell University. This leaf, if similarly bent, can be fitted into the plications of the fossil. Despite the scantiness of the material this species appears to be reliably identified.

The coconut palm is now very abundant on the island, mostly planted. It is generally regarded as being of human introduction on the oceanic islands of the Pacific, although

Fig. 6. *Miscanthus floridulus*, part of mass of leaf blades, showing venation.

Fig. 7. *Cocos nucifera*, portion of seedling leaf, showing plication.

the possibility of the establishment of drift nuts is not denied. In all probability the present seedling was from progeny of trees introduced by early human visitors to Pagan, indicating that the horizon in which it occurs may be rather recent.

ARACEAE

Alocasia macrorrhiza (L.) Schott

PC-43–1 (a–f), 2, 3, 5

A very well-preserved mold of a petiole, a fragment of the upper part of a petiole, various badly crushed and damaged petiole fragments and a stipule, not especially well preserved. Some of these petiole fragments would have been quite unidentifiable by themselves but were recognized when associated with the other better preserved parts (Fig. 8).

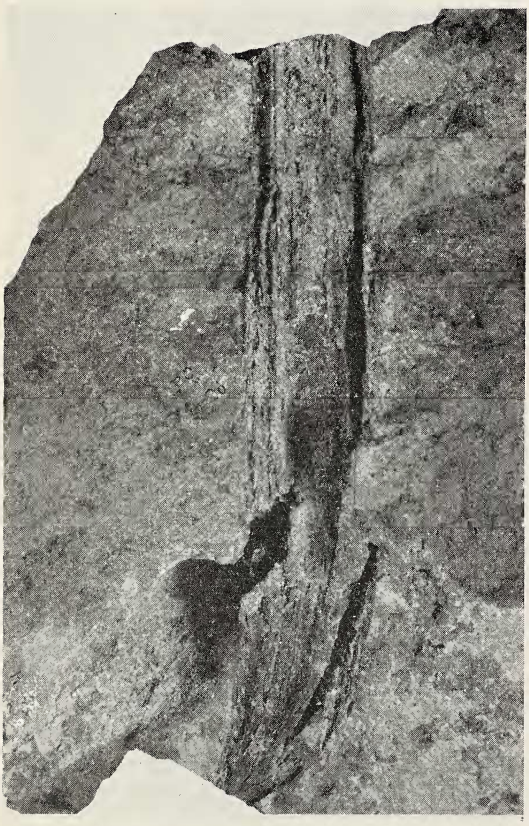

FIG. 8. *Alocasia macrorrhiza*, stipule.

This plant is found throughout the Pacific islands wherever man has carried it. It has not been found where it could not readily have been originally planted by man. The aborigines in many islands are said to utilize it as a famine food, though it is not very palatable. It has no obvious means of getting around unaided, but once established persists and multiplies rather successfully.

Its presence in this fossil flora is distinctly surprising. It indicates that the eruption producing the tuff, which preserved the remains, occurred after the earliest visits by man to the island.

LILIACEAE

? *Dianella ensiformis* (L.) DC.

PC-85–1, PC-85–2, ID2(F)-3, 4

Leaf blade impressions and fragments of impressions. Where the outline is preserved these taper more strongly than in *Miscanthus;* where venation is evident there is a prominent midrib and fine even venation, the veins of equal thickness, between 3 and 4 per mm. (Fig. 9).

This is not known from Pagan as a living plant, though it may well have been overlooked. It is common elsewhere in the Marianas in swordgrass vegetation on volcanic soils, especially on old erosion scars and around rocky places.

ORCHIDACEAE

? *Spathoglottis micronesiaca* Schltr.

ID2(F)-7

A reasonably well-preserved impression of a leaf fragment showing strong plication of about the magnitude of that shown by this species, the width and what remains of the shape, also, being correct. The specimen is 3 cm. wide and has just under 3 plications per cm. (Fig. 10).

This species is common in the grassland in the volcanic portions of Guam. It is not known at present on Pagan unless a pink-flowered plant noted but not collected by Bonham is it.

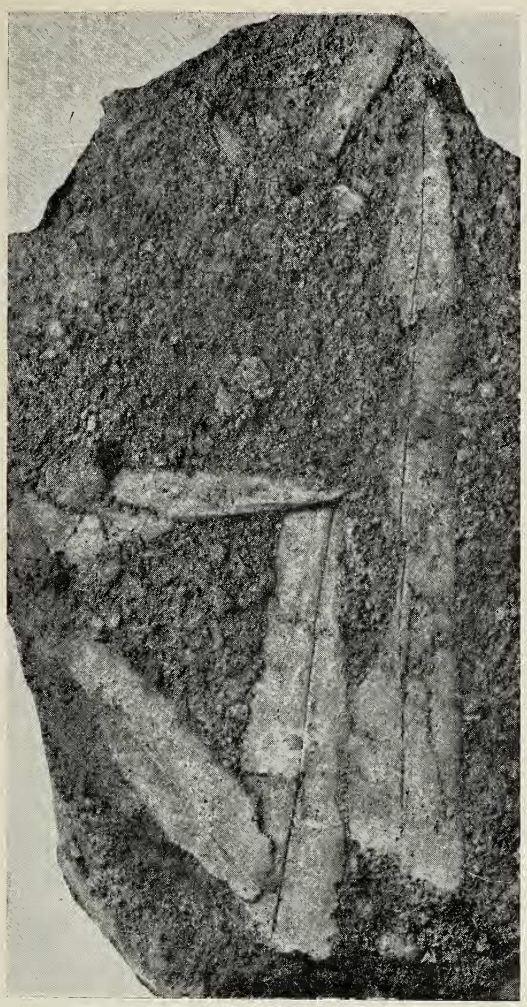

Fig. 9. ? *Dianella ensiformis*, leaf blades.

ULMACEAE

Trema argentea Planch.

PC-79–11

A partial leaf impression with palmate and net venation so perfectly preserved that there is little or no doubt as to its identity with *Trema argentea*. A piece of the opposing part of this impression is preserved on PC-79–12 (Fig. 11).

This plant, which is often and possibly correctly regarded as a variety of *Trema orientalis*, occurs throughout the Marianas, including Pagan, and north through the Volcano and Bonin islands, and with related forms in continental Asia.

It probably may be regarded as one of the few northern elements of the flora of the Marianas; and the present fossil fairly well disposes of the possibility of it being a recent introduction in the Marianas.

Fig. 10. ? *Spathoglottis micronesiaca*, portion of leaf blade showing plication.

HERNANDIACEAE

Hernandia sonora L.

PT-7–1

A portion of an impression of a leaf blade with major veins well shown and with some indication of texture. The appearance of a firm, stiff texture, palmate venation with veins somewhat impressed, and the distance between the base and the first branches from the midvein strongly suggest this species. It is a pantropic lowland or strand tree, common in the Marianas and known from Pagan.

EUPHORBIACEAE

? *Macaranga thompsonii* Merr.

PC-79–12

A poorly preserved impression of part of a leaf showing some major palmate venation.

FIG. 11. *Trema argentea*, portion of leaf, showing venation.

Viewed by itself it would be scarcely identifiable, but when placed side by side with a leaf of this species the correspondence of the venation pattern is striking.

This is a tree commonly found in the southern Marianas, especially in second growth and pioneer situations, but more often on limestone than on volcanic soils. It is not known to be living on Pagan at the present time.

Melanolepis multiglandulosa (Reinw.) Reichenb. f.

PC-86–2

A fragmentary leaf impression showing the main veins. The palmate and net venation pattern checks very well with that of this species, which is common on Pagan as in the rest of the Marianas, extending to Indonesia. It grows in thickets and secondary scrub forest.

MELIACEAE

Aglaia mariannensis Merr.

PT-7–3

Several imperfect impressions of leaflets, some showing pinnate venation. The veins are rather straight and strongly ascending. The shape of leaflets of this species varies from elliptic to obovate and that of the fossils shows corresponding variation as much as could be expected in the meager material available (Fig. 12*a*).

This is one of the commonest species of small trees in thickets as well as forests throughout the Marianas, including Pagan. Related species are found elsewhere in Micronesia and westward.

SAPINDACEAE

Tristiropsis obtusangula Radlk.

PC-58–1 (a–e), PT-7–2, 5

Impressions of leaflets, mostly imperfect, apparently somewhat folded along midribs, rather stiff, some of them showing main venation of a pinnate character. Some of the more poorly preserved of these impressions may belong to *Aglaia*, but the oblique bases of most of them scarcely fit that genus (Fig. 13).

Tristiropsis obtusangula is at present known only from Guam and Rota and grows usually but not always on limestone.

TILIACEAE

Elaeocarpus joga Merr.

PT-7–4

A practically perfect leaf impression, obovate, showing a short petiole and some venation (Fig. 12*b*).

This species extends throughout the Marianas as far north as Pagan. In the southern Marianas it grows on limestone but in the north on lava flows. It is a large forest tree. Closely related species are found in other parts of Micronesia and the Philippines.

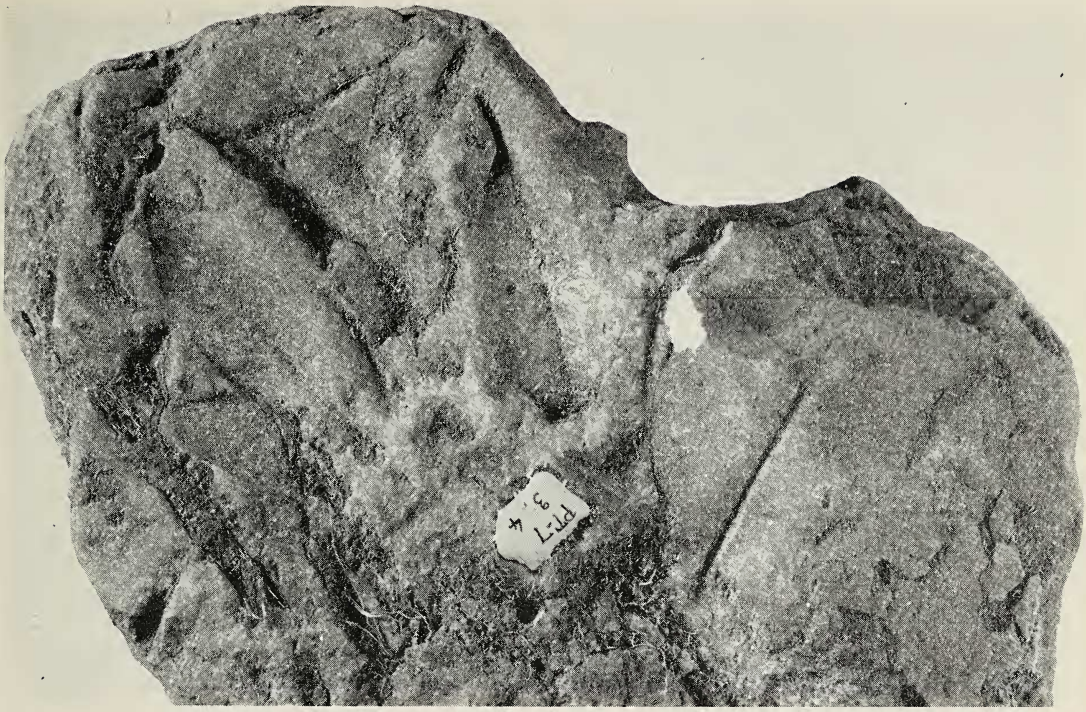

Fig. 12. *Aglaia mariannensis*, impression on right, base of large leaflet, that on left, possibly one of smaller leaflets. *Elaeocarpus joga*, impression in center, leaf blade and petiole.

THEACEAE

? *Eurya nitida* Korth.

PC-79–10

Two fragmentary leaf impressions, not positively identifiable. Only bases, with some obscure venation, and rather curious minute surface marking are available. *Eurya* seems the most likely identity.

This is a small-leafed shrub or small tree, characteristic of volcanic soils and frequently found isolated or in small thickets in swordgrass areas. It has been reported from Pagan by Hosokawa as *Eurya ladronica* Hosokawa.

VERBENACEAE

Premna obtusifolia R. Br.

PC-86–1

A good leaf impression with venation rather clearly shown but lacking the apex (Fig. 14). It is much smaller than the average for this species but matches well enough some of the smallest leaves present on available herbarium material. The angle of divergence of the main veins is so wide as to preclude its belonging to most of the other Micronesian species with palmate venation, the only possibilities being *Thespesia populnea* (L.) Sol. ex Correa, which it does not resemble in other characteristics and which is rarely so small, and *Sida fallax* Walp., which has never been reported from the Marianas.

Premna obtusifolia is a very common tree throughout the Marianas, including Pagan, growing in thickets or secondary growth as well as in original forest. The species is variable and extends over much of the Indo-Pacific region. It has been given various names, the one most commonly used for Marianas material being *Premna gaudichaudii* Schauer.

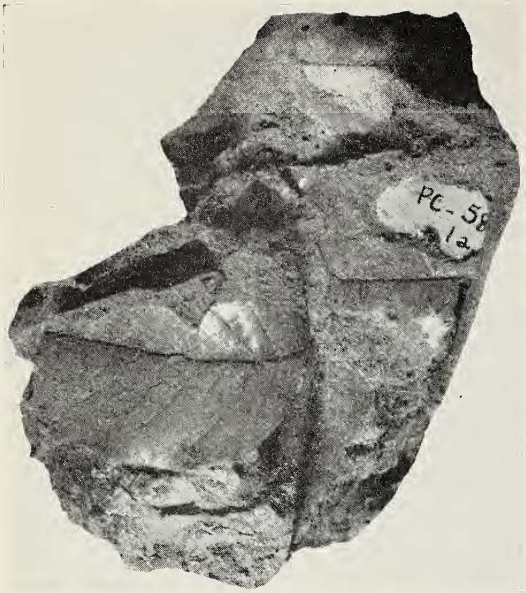

FIG. 13. *Tristiropsis obtusangula*, impression of leaflet, showing texture and venation.

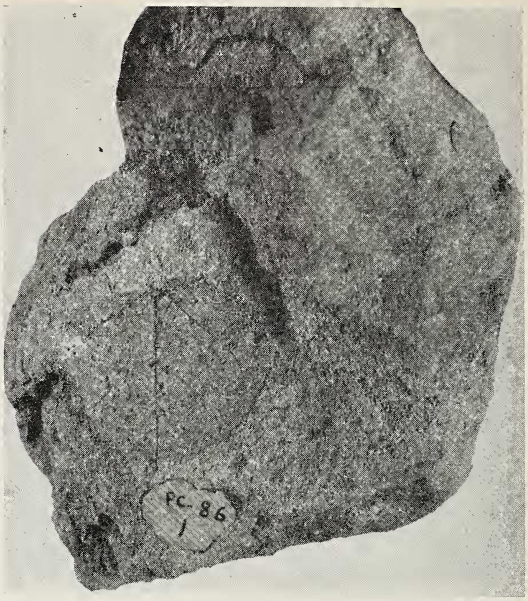

FIG. 14. *Premna obtusifolia*, an unusually small leaf blade, with apex missing, showing venation.

Family unknown

Unidentified impression, probably a leaf scar.

ID2(F)-5

This is a concave impression, more or less shield shaped, with 5 (or 6) bundle traces.

Unidentified mold of a fruit or curved leaf.

PC-86–3

This hollow curved impression, lacking suggestive details, was not matched with anything.

PALEOECOLOGY

By listing the species identified from each of the samples it is possible to suggest something of the probable ecological conditions and vegetation types at the time the various deposits represented were laid down. Such conclusions are, of course, extremely tentative when based on so few species. It is greatly hoped that at some future time more extensive collecting may be done in these beds so that the picture of the past vegetation and conditions on the island may become clearer.

Sample PC-43

Pandanus tectorius, *Miscanthus floridulus*, *Alocasia macrorrhiza*

It is hard to associate *Alocasia* with swordgrass except where the *Alocasia* might have been in a somewhat shaded ravine bottom, perhaps with *Pandanus* trees, and with the sides of the ravine covered with swordgrass, possibly extending down almost to the bottom of the ravine. On more level ground, if it is not too dry, the *Alocasia* could have grown in a thicket of *Pandanus* and possibly other trees, closely surrounded by swordgrass. The *Alocasia* suggests the presence or former presence of man, as this plant was in all probability distributed in the Pacific islands entirely through human agency.

Sample PC-48

Miscanthus floridulus

Probably swordgrass vegetation.

Sample PC-58

**Tristiropsis obtusangula*

This is a forest tree, not now found on

* Not now known to be living on Pagan.

Pagan or in the northern Marianas but common on rough limestone on Guam. An association of plants similar to that in which this species grows on Guam occurs on rough lava in the northern Marianas on Alamagan Island, which is much like Pagan. Something like this association may have existed on rough lava in pre-caldera time on Pagan.

Sample PC-79

Pteris quadriaurita, *Pandanus tectorius*, *Freycinetia mariannensis*, *Miscanthus floridulus*, *Cocos nucifera*, *Trema argentea*, ? **Macaranga thompsonii*, ? *Eurya nitida*

From the assemblage of plants represented here the habit could have been the margin of a mixed thicket, possibly second growth, bordering on swordgrass. The presence of a seedling coconut suggests the possibility of human disturbance.

Sample PC-84

Miscanthus floridulus

The vegetation indicated is swordgrass.

Sample PC-85

? *Freycinetia mariannensis*, *Miscanthus floridulus*, **Dianella ensiformis*

Swordgrass vegetation close to either a thicket or a rock cliff, unless what are here identified as *Freycinetia* leaves are really *Pandanus*, in which case it would have occurred as scattered trees or thickets in the swordgrass.

Sample PC-86

Pandanus tectorius, *Miscanthus floridulus*, *Melanolepis multiglandulosa*, *Premna obtusifolia* Unidentified mold.

Probably swordgrass with mixed thickets or patches of scrub forest of *Pandanus* and broad-leafed trees.

Sample PT-7

Hernandia sonora, *Aglaia mariannensis*, *Elaeocarpus joga*, ? **Tristiropsis obtusangula*

This association suggests a forest of the sort that grows on rough lava on such islands as Alamagan at the present day, or on rough limestone on the islands farther south.

Sample ID2 (F)

Pandanus tectorius, *Miscanthus floridulus*, **Dianella ensiformis*, **Spathoglottis micronesiaca* Unidentified leaf scar or fruit impression.

The conditions suggested by this small flora are those of swordgrass, possibly somewhat sparse, with either thickets or scattered trees of *Pandanus*.

Sample $ID3_1$

Miscanthus floridulus

Probably swordgrass vegetation.

From the foregoing lists it will be seen that there is meager evidence for any comprehensive opinions on the past vegetation of Pagan. Most of the indications are that at least some of the vegetation was much the same as that found on the island today. Swordgrass occurs in all but the two lowest horizons, and there is little doubt that it dominated the vegetation wherever there was a loose ash substratum. Undoubtedly there were scattered trees or clumps of *Pandanus* and probably mixed thickets and scrub forest of *Pandanus* and other trees. Although the coconut does not appear in most of the lists of species, it may very well have been present in all of the later horizons, as there is little doubt that it was introduced by the early Chamorros and no reason why it would not have persisted whether or not they inhabited the island for any great length of time. An interesting fact is the complete lack of *Casuarina* in the collections. Next to *Miscanthus* it is the most abundant component of the modern vegetation of the island. It adds to the scanty evidence that *Casuarina* may be a recent arrival in the Marianas, but this is still an unsettled question.

The two lowest horizons, with plants commonly found on rough lava or rough limestone and with one tree not known today on Pagan, possibly represent a slightly more mature vegetation than any known at present on the island, though it may actually be represented in the mixed forest type. Something like it is prominent on extensive rough lava

flows on Alamagan, the next island to the south of Pagan. The violent explosive eruptions that formed the calderas and deposited the thick tuffs may have completely destroyed the stands of this type of forest.

The presence of four species in the fossil collections that are not known to be living on the island today may possibly have little significance, for the living flora has not been really well collected and those species may actually be present now. However, on an island with frequent and at times violent volcanic activity the continued existence of any but the most tenacious species of plants is hazardous, and it is more than likely that some that were once growing on Pagan may have been eliminated.

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